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The Discrimination of CV Synthetic Syllables as a Function of Phonetic Training and Noise Conditions

Ryan Mulligan
ryan.mulligan2@va.gov

Antony Joseph
Illinois State University, arjosep@ilstu.edu

THE DISCRIMINATION OF CV SYNTHETIC SYLLABLES AS A FUNCTION OF PHONETIC TRAINING AND NOISE CONDITIONS

Capstone Document

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By

Ryan C. Mulligan, B.S.

Illinois State University

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Capstone Committee:	Approved By
Antony Joseph, Ph.D., Au.D., Advisor	______________________________
Joseph Smaldino, Ph.D., Advisor	______________________________
Ann Beck, Ph.D., Department Chair	______________________________

ABSTRACT

The aim of this preliminary study was to examine the effect of two signal-to-noise ratios (SNR) and formal phonetic training on auditory discrimination of just noticeable differences (JND) among consonant vowel (CV) synthetic syllables. Fine-grain auditory discrimination abilities of 16 young-adults with undergraduate studies that included phonetic training and 17 young-adults with no phonetic training were assessed using a *same/different* discrimination task in a +3 SNR and a +13 SNR listening condition. Subjects listened to pairs of CV contrasts presented in rapid succession and indicated whether the contrastive syllables were the *same* or *different*. Results revealed a significant difference in discrimination performance between acoustic conditions, with less discrimination errors made in the more favorable SNR condition. Two conclusions were drawn from this finding. First, it was inferred the use of a classroom audio distribution system, which typically provide a 10 dB relative advantage over unamplified listening conditions, may improve fine-grain auditory discrimination. Second, it was concluded that speech language pathologists who rely upon their perceptual abilities to perform speech sound analysis of speech sound disorders, might benefit in terms of diagnostic accuracy and precision from a SNR of at least 10 dB. Lastly, results revealed a greater than 4% difference in discrimination performance between subject groups in the +13 SNR condition; however, the difference was not statistically significant. Additional studies with larger samples sizes might yield more robust inferential data.

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VITA

Ryan C. Mulligan

November 1, 1987……………………………………………...Born – Crystal Lake, IL

May 2007……………………………………Diploma – Crystal Lake South High School

December 2011…………………………………………B.S., Speech Language Pathology

Illinois State University

January 2012 – July 2012……………………………………ESL Teacher, Taipei Taiwan

August 2012 – Present……………………………Doctoral Student/Clinician, Audiology

Illinois State University

June 2015 – July 2016 (Expected)…………………Audiology Resident, VA Health Care

System, San Diego, CA

Fields of Study

- Minor Field: Speech-Language Pathology
- Major Field: Audiology

Research and Clinical Interests

- Speech Perception
- Aural Rehabilitation
- Vestibular Evaluation & Rehabilitation

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CHAPTER 1

Introduction

This preliminary capstone study was spurred by two independent, but clinically pertinent, research questions. First, the author aimed to examine whether an increased signal-to-noise ratio (SNR), such as observed with the use of classroom audio distribution system (CADS), can enhance fine-grain auditory discrimination. Second, the author aspired to learn whether phonetic training can improve the detection of fine-acoustic cues that signal consonant contrasts. In order to provide the reader with an understanding of the impetuses of this study, a discussion regarding pertinent speech perception concepts and auditory discrimination in school age children and phonetically trained adults is provided below.

Literature & Study Overview

Speech perception requires listeners to make categorical judgments and selectively attend to meaningful differences between speech sounds. The ability to differentiate between individual speech sounds is referred to as speech discrimination (Wepman, 1960). It is generally accepted that speech discrimination is governed in part by categorical perception. Categorical speech perception describes the phenomenon by which acoustic changes along a continuum are perceived categorically rather than continuously. When listeners are presented with a continuum of speech sounds (e.g. ba & ga) and are tasked with identifying items as belonging to discrete categories, their perception abruptly shifts from one category to another at perceptually distinct points along the continuum[1].

Liberman, Harris, Hoffman, and Griffith (1957) were the first to demonstrate that speech sounds (phonemes) are perceived categorically. In their seminal study conducted at Haskins Laboratories, an ABX task (i.e. X stimulus is compared to A and B stimulus) was used to assess subjects' ability to discriminate between sounds that fell outside and within phonemic categories. Three synthetic speech sounds (/be/, /de/, and /ge/) were varied across an acoustic continuum. By varying the onset frequency of the second formant transition, 14 speech sounds were created with equal acoustic spacing between adjunct sounds. Participant heard three consecutive stimuli (i.e. A followed by B followed by X) and indicated whether the last stimulus X was identical to the A or to the B stimulus. Subjects' performance was more accurate for outside phonetic category comparisons than for within phonetic category comparisons. Liberman et al. concluded listeners are much better at discriminating stimulus pairs that belong to different phonetic categories (interphonemic) than stimulus pairs that belong to the same phonetic category (intraphonemic).

Research related to categorical perception continued at Haskins Laboratories for several decades. Starting in the 1960s, researchers began investigating the relationship between speech discrimination and language impairments. Numerous studies indicated that children with specific language impairment (SLI) have deficits of temporal processing and discrimination (Aten & Davis, 1968; Lowe & Campbell, 1965; Stark, 1967; Monsees, 1968). For example, Lowe and Campbell (1965)

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[1] It should be noted that vowels like non-speech sounds are perceived in a more continuous than categorical-like mode (Altmann et al., 2014; Pisoni, 1973; Pisoni, 1975).

investigated the temporal ordering ability of children with and without developmental aphasia[2]. Two different tones (400 Hz and 2200 Hz) with brief inter stimulus intervals (ISIs) were presented in rapid succession, and subjects were asked to indicate which of the two tones they heard first. The control group required a mean ISI of 250 msec to accurately (defined as 75%) discriminate between tones, whereas the children with aphasia required a mean ISI of 40 msec to achieve a similar level of performance as the controls. Lowe and Campbell (1965) demonstrated children with language impairments have deficits of auditory temporal discrimination.

Tallal and Piercy (1973) replicated the findings of Low and Campbell (1965) using a similar auditory processing task. Children with and without developmental aphasia heard two different tones presented sequentially and were asked to (1) indicate the temporal order of the tones (high versus low) and (2) whether the two tones were the *same* or *different*. On the ordering task, the control children performed at level significantly better than chance with ISI of 8 milliseconds (msec), whereas the children with aphasia required intervals of 305 msec or greater in order perform at the *same* level of performance as the controls. Similarly, during the *same/different* discrimination task, children with aphasia required intervals of 305 msec to discriminate between the tones. Tallal and Piercy theorized that children with language impairments are unable to discriminate between stimuli that are presented at rapid rates and discrimination deficits may contribute to delayed language development.

Stimulated in part by the work of Tallal and coworkers, Lois Elliot and

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[2] "Developmental aphasia" is a historic term for children who would currently meet the clinical criteria for SLI.

colleagues began a large field study to estimate the prevalence of auditory discrimination deficits in young school-age children and to examine longitudinal changes in auditory discrimination in children with and without language impairments. Lois Elliott and colleagues reported the field study's findings in several published articles (e.g. Elliott & Hammer, 1988; Elliott, Hammer, & Scholl, 1989; Elliott, Hammer, & Scholl, 1990). One of their most salient findings was "fine-grain" auditory discrimination measures could be reliably used to predict whether children will have language-learning difficulties (Elliott, Hammer, & Scholl, 1989). Elliott, Hammer, & School (1989), used a *same/different* response paradigm to assess subjects' discrimination of just-noticeable differences [the smallest perceivable differences (JNDs)] among synthetic CV syllables presented in rapid succession (500 msec ISI). Fine-grain auditory discrimination measures correctly categorized (with 79% accuracy) children as exhibiting language learning problems or having normal language development. The results were supported by earlier reports that indicated children with language impairments have particular difficulty discriminating stimuli that contain rapidly changing acoustic cues (Tallal & Piercy, 1975; Tallal & Piercy, 1974; Tallal, Stark, & Mellits, 1985). Based upon the result of the study, Elliott, Hammer, and Scholl (1989) suggested that poorer than normal discrimination of frequency and temporal differences may lead to perceptual confusion or misunderstandings (e.g. "doll" for "ball", "die" for "tie", "tug" for "dug" etc.), thereby resulting in improper productions and word usage, and ultimately impaired language development. Although Elliot and colleagues abstained from reporting a causal relationship between poorer than normal auditory discrimination and delayed language development, they hypothesized that the ability to discriminate between subtle speech sounds is critical for both language learning and academic success, particularly among elementary school-aged children (Elliott, Hammer, & Scholl, 1989).

Based upon the premises that fine auditory discrimination affects early language learning and academic progress, and auditory discrimination is affected by the acoustic integrity of a signal, Elliot, Hammer, and Scholl (1990) argued that classroom learning could be enhanced by providing children with the best-possible classroom listening environment. It is well known that spoken instruction within a classroom listening environment is susceptible to several potentially corrupting acoustic variables, including background noise, distance from teacher-to-student, directionality, and reverberation (i.e. the reflection of sound waves off multiple surfaces), and the combined effect of these variables. In order to decrease the negative effects of background noise and teacher-to-student distance, amplification technologies, such as classroom audio distribution systems (CADS), have been employed in a variety of classroom settings.

To date, only one study has examined the effects of CADS on "fine-auditory" discrimination. Smaldino, Green, & Nelson (1997) investigated the effects of a classroom audio distribution system (CADS) on the ability of young-adults to discriminate between phonetic sound differences in a college classroom. Thirty-one college students enrolled in a phonetics course completed a phonetics listening test in amplified and unamplified listening conditions. Subjects transcribed the sounds they heard and the number of phonetic errors made by the subjects were calculated for each condition. The results indicated a significant difference in the number of errors made in unamplified versus amplified listening conditions. The investigators concluded that CADSs can significantly enhance fine-auditory discrimination in classroom environments. While the findings of Smaldino, Green, & Nelson (1997), suggest that discrimination of phonetic cues are enhanced by a CADS, the study did not address whether CADS can increase discrimination of the smallest perceivable acoustic differences (JND) that signal constant contrasts. Such fine-acoustic cues are thought to hold special importance for language learning and school success (Elliott, Hammer, & Scholl, 1989; Tallal, 1990) and are present in the second-formant transition periods of stop consonants[3].

The present study was designed to examine whether an improvement in SNR, such as provided by a CADS, can improve discrimination of CV synthetic syllables that differ according to their second formant transitions. It is well known that low energy and high frequency consonants, such as the stop consonants employed in the present study (i.e. /b/, /d/, /g/), are especially susceptible to the masking and distortion effects of noise (Ning and Loizou, 2008; Parikh & Loizou, 2005; Phatak and Allen, 2007). Therefore, it seems logical that an improvement in the SNR would result in greater perceptual detection and resolution of fine-acoustic cues (i.e. JND) and ultimately, enhance CV discrimination performance.

A secondary goal of this study was to examine the effect of formal phonetic training on fine-grain discrimination, or, more precisely, whether phonetically trained

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[3] Formants reflect vocal resonance within the oral cavity. Tongue elevation and lip rounding largely determine the amplitude spectrum of the second formant. Stop (plosive) consonants such as /b/, /d/, and /g/ acoustically differ only in terms of their second formant transitions.

listeners have enhanced discrimination sensitivity of second-format transition cues. Phonetic instruction typically includes learning the method in which speech sounds (phonemes) are produced (articulatory phonetics) and perceived (auditory phonetics). Students majoring in Speech-Language Pathology (SLP) typically receive a semester-long articulatory-phonetics course with an emphasis in phonetic transcription. Students are trained to analyze, identify, and phonetically transcribe normal and disordered speech.

Speech-language pathologists (SLPs) rely upon their phonetic training and perceptual abilities to evaluate and treat articulation and phonological disorders. Both speech disorders are characterized by speech sound errors. The accurate assessment and treatment of speech disorders requires clinicians to discriminate between normal and error sound productions. For example, in the case of common substitutions errors, such as /t/ for /k/, /d/ for /g/, or /w/ for /r/, clinicians must detect and discriminate acoustic cues that signal contrasts. Evidence suggests the fine-acoustic cues that signal consonant contrasts are often difficult for both clinically trained and untrained listeners to accurately perceive (Chaney, 1988; Monnin & Huntington, 1974; Sharf, Ohde, Lehman, 1988; Wolfe, Martin, Borton, & Youngblood; 2003). Misarticulations that fall within phonemic boundaries or close to phonetic boundaries (category transition points) are especially prone to misidentification[4]. For example, several studies have shown that speech language pathologists have considerable difficulty distinguishing between graduations of distorted /r/ productions (Monnin & Huntington, 1974; Sharf & Ohsw, 1983; Sharf, Ohde, & Lehman, 1988). This is

[4] The point along an acoustic continuum at which perception shifts from one phonetic category to another is referred to as the phonetic boundary.

clinically relevant because clinicians who cannot perceive graduations in speech sound correctness or cannot accurately discriminate between correct and incorrect sound productions may misidentify speech sounds, and, consequently, lose diagnostic accuracy and precision. Furthermore, treatment approaches that involve feedback regarding client speech sound accuracy, such as the successive approximation treatment, are necessarily contingent upon the clinician's ability to discriminate between subtle graduations in speech sound correctness. For example, in the case of successive approximation therapy, the clinician progressively "shapes," via reinforcement, a target sound (e.g. /r/) from a standard sound (e.g. /l/) that is in the client's phonetic inventory. The treatment method is dependent upon the clinician's ability to perceive fine-difference in intraphonemic productions and provide appropriate reinforcement based upon the client's level of sound approximation. If a clinician fails to accurately perceive intraphonemic approximations, that clinician may be unable to provide appropriate remediation.

Given that discrimination of subtle speech sounds play a notable role in the diagnosis of speech disorders which factors significantly into the effective provision of treatment, the question of whether phonetic training can improve fine-grain discrimination appears to be of clinical merit. A literature search revealed no studies have examined the relationship between phonetic training and the discrimination of JNDs; however, several studies have indicated that clinically-trained listeners have increased sensitivity to fine-phonetic cues (Hillenbrand, Cantar, & Smith, 1990; Munson, Johnson, & Edward, 2012; Wolfe et al., 2003). For example, Munson, Johnson, and Edwards (2012) investigated differences in perception of children's speech among 21 practicing SLPs who were trained in phonetics, and 21 non-clinically trained listeners. Subjects rated their perception of children's productions of target sounds /t/–/k/, /s/–/θ/, and /d/–/g/ using a visual analog scale. The results revealed that experienced clinicians had more reliable and valid representations of the target sounds than non-clinicians. Based upon these findings, Munson and coworkers (2012) proposed that fine-grain auditory perception is influenced by listening experience and the ability to differentiate between subtle sounds may be learned. The authors reported, "The present study shows clearly that experienced listeners are better able than inexperienced listeners to perceive fine phonetic detail in children's speech, setting the stage for systematic studies of how to best facilitate the learning of these skills (pg. 136)."

While there is evidence that phonetically trained listeners have improved discrimination of *inter*-and *intra-phonemic* differences, it is unknown whether phonetic training can improve discrimination of *fine-acoustic* differences (JND) characterized by rapid formant transitions. That is, it is not clear whether discrimination of the smallest spectrotemporal elements in speech sounds may be enhanced by phonetic training. Considering the evaluation and remediation of disordered speech requires clinicians differentiate between subtle difference in speech sounds, the question of whether fine-grain discrimination is influenced by phonetic training warrants further study.

Research Questions

To summarize, the primary purpose of this study was twofold:

1. Investigate the effect of two SNRs typical of CADS "on" and "off"

listening conditions on the discrimination of JNDs among stop consonant contrasts.

2. Explore whether phonetically trained listeners are more sensitive to fine-grain discrimination cues than untrained listeners.

CHAPTER 2

Methods

Subjects

Thirty-three ISU students, including 24 females and 9 males, ranging in age from 18 to 29 years of age, with a mean age 22.7 years (SD 9), participated in this study. Subjects were assigned into one of two groups. Group One (G1) was comprised of 16 graduate students (mean age 23.3 yrs.), including 14 females and 2 males subjects enrolled in speech-language pathology or audiology graduate programs within the Department of Communication Sciences and Disorders (CSD). Subjects in G1, had already successfully completed an undergraduate clinical phonetics course. Group two (G2) was comprised of 17 undergraduate and graduate students (mean age 22.1 yrs.), including 10 females and 7 males who had not received phonetic training. All the subjects met the following inclusion criteria (1) ≥ 18 years of age, (2) native English speaker, and (3) pure-tone thresholds of ≤ 20 dB HL at octave frequencies 250-8000 Hz. Subjects learned of the study through word of mouth, recruitment emails, and flyers which were distributed on campus. The Illinois State University (ISU) Institutional Review Board (IRB) approved the study prior to data collection and informed consent was obtained from each participant in accordance with ISU IRB guidelines (IRB number 2013-0310).

Apparatus

Hearing screening and experimental testing took place in a stationary double-walled sound-enclosure. The sound-booth was certified and met sound pressure levels specified by the American National Standard for Maximum permissible Ambient

Noise Levels for Audiometric Test Rooms (ANSI S3.1-1999). Sound-booth acoustics met ANSI acoustics criteria for classroom reverberation time and background noise (ANSI S12.60-2002). Recorded stimuli were routed from a dual-disc CD player (Sony Disc Ex-change System 8846433) to a calibrated clinical diagnostic audiometer (Grayson Stadler GSI 61 #1071), and presented binaurally via regular 13 mm insert-earphones (Etymotic Research Model ER-3A). The audiometer described above was in compliance with ANSI Specifications and Reference Threshold Values for Audiometers (ASNI S3.6-2010).

Stimuli

Experimental stimuli consisted of three synthetic speech sounds: [ba], [da], [ga]. The stimuli were chosen in order to evaluate subjects' ability to discriminate between rapid spectrotemporal changes (i.e. just noticeable differences [JNDs]) among stop-consonant vowel (CV) syllables. Synthetic CV syllables have been employed in previous auditory discrimination studies (e.g. Bradlow et al., 1999; Cutting, Rosner, & Foard, 1976; Elliot et al., 1981; Elliott, Hammer, & School, 1990; Kraus et al., 1999; Pisoni, 1973, Sussman, 1993; Tallal, Stark, & Mellits, 1985) and are considered acceptable tokens of natural speech (Elliott, Hammer, & Scholl, 1989; Tallal & Piercy, 1974).

The same stimuli used by Hornickel, Skoe, Nicol, Zecker and Kraus (2009) were used in this study. Experimental stimuli were generated using a KLATT parallel/cascade synthesizer (Klatt, 1980) using parameters corresponding to a male voice. Stimuli consisted of six-formant CV syllables that varied according to trajectory of the transition period of second formant. Stimuli sounds may be characterized temporally as being 170 msec long, with a 120 msec steady state vowel and a 50-msec formant transition. Voicing onset occurred at 5 msec and second formants contained either downward ([ba],[da]) or upward ([ga]) spectral shifts. Second formants fell from 2480 to1240 Hz and from 1700 to 1240 Hz for the stimulus [ga] and [da] and rose from 900 to 1240 Hz for the stimulus [ba]. Frequencies for the first (F_0), fourth, fifth and sixth formants were constant at 100, 3300, 3750, and 4900 Hz, respectively (Hornickel et al., 2009). More detailed information regarding the acoustic parameters of the stimuli used in this study is reported in Hornickel et al., 2009.

Stimuli WAV files were downloaded onto a Microsoft OS X computer. Two stimuli tracks were created with the use of an audio-editor program (Audacity 2.0.6). Each track contained CV syllables that were grouped into 180 trials (i.e. CV contrast pairs). The following CV pair sequences were randomly varied on each track: [ba-ga], [ba-da], [ba-ba], [da-ga], [da-ba], [da-da], [ga-ba], [ga-da], [ga-ga]. CV sequences contained an inter-stimulus interval (ISI) of 500-msec and each trial was separated by 6-second intervals.

For both tracks, a recorded female voice provided a counting sequence that preceded the onset of every 5th discrimination trial by 3 seconds (i.e., a spoken number “one” could be heard before trial number 1 and a spoken number “five” could be heard before trial #5, etc.). Each track contained a 30-second long 1000 Hz calibration tone that was equated to the root mean square (RMS) value of the stimuli. Stimuli tracks were burned onto a compact disc (CD) using a 44100 Hz sample rate with 24-bit resolution.

Auditory Discrimination Task and Procedures

Prior to the data collection, subjects read and signed a consent form (Appendix A) and completed a survey (Appendix B). Subjects were asked to indicate their gender, age, college major, and phonetics training (if applicable). Phonetically-trained subjects were asked to indicate when they completed their phonetics training (e.g., Fall, 2012) and their perceived phonetic proficiency. Subjects were allowed to choose from the following phonetic proficiency categories: (1) very proficient, (2) proficient, (3) can get by, (4) not proficient. Following the completion of the survey, instructions were read to subjects (Appendix D). Subjects were instructed to mark an "A" on their Scantron sheet if stimuli pairs were judged to be the *same* and "B" if stimuli pairs were judged to be *different*. They were also instructed on the number of discrimination trials and conditions, and time length of the task (Appendix C). Subjects in both groups were encouraged to ask questions if they did not understand the task.

Once the signed consent form and participant survey had been collected, a pure-tone hearing screening was administered. Pure tones were presented at 20 dB HL at octave frequencies of 250-8000 Hz via insert earphones. All subjects had pure-tone sensitivity that was better than or equal to 20 dB HL at 250-8000 Hz, bilaterally. Upon completion of the pure-tone screening, speech stimuli were calibrated to 0 dB with the use of the audiometer's volume unit (VU) meter. Following calibration, with insert- earphones in place, subjects were given a clipboard, pencil, and a Scantron sheet, and were instructed that the discrimination task would begin shortly.

The discrimination task was divided into two conditions each containing 180 discrimination trials. Each trial type (e.g. /ba-da/) was present an equal amount of times (n = 20 per condition)[5]. Stimuli tracks were counterbalanced across conditions. In both conditions, stimuli were presented binaurally at 60 dB HL. The stimulus presentation level was chosen in order to represent the typical speech level of a classroom teacher (Anderson, 2010). Continual speech-shaped noise was presented binaurally and counterbalanced across conditions. Speech-shaped noise was selected in order to represent competing speech-to-noise in a classroom environment (e.g., student "side talk"). The speech-shaped noise matched the average spectrum of conversational speech and contained an equal amount of energy from 250-100 Hz with a 12 dB octave roll-off from 1000-6000 Hz (GSI Manual, 2005).

Subjects were presented 180 trials with a signal-to-noise (SNR) ratio of +3 dB (i.e., noise level of 57 dB HL) and 180 trials with a SNR of +13 dB (i.e., noise level of 47 dB HL). According to Crandell, Smaldino, and Flexer (1997), and Larsen and Blair (2008), classroom audio distribution systems (CADS) typically improve the SNR by approximately 10 dB. Thus, in order to represent CADS *on* (amplified) and *off* (unamplified) acoustics, two SNRs that differed by 10 dB were chosen (+13 SNR and +3 SNR).

The discrimination task was 36 minutes long. Each condition was approximately 18 minutes long and subjects were provided a 1-minute resting period between discrimination conditions. During this resting period, the investigator provided brief verbal reinforcement (Appendix D). Upon completion of the discrimination task, the investigator collected the participant's Scantron sheet and

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[5] Note: all item types were presented an even number of times, thus, there were 2 times more *different* than *same* trials included in the discrimination task.

debriefed the subject.

CHAPTER 3

Results

The demographic characteristics of the recruited sample have been displayed in Table 1. Of the 33 total study participants, Group 1 was comprised of 16 subjects with a mean age of 23 years, and Group 2 included 17 subjects with a mean age of 22 years. From this, we may conclude that the sample size of the groups was equivalent and the age of subjects in the groups were also equivalent. A difference was observed for gender, in that, there were far more female subjects (24) than male subjects (9) recruited for the investigation, which is reflected in Table 2. It is well known that the field of Communication Sciences and Disorders is largely female, so male subjects must be recruited outside of the department. In this case, females (mean age 22 years) were almost three years younger than males (mean age almost 25 years). Overall, the females were in the age group of upper-class undergraduates and the males were in an age group associated with graduate students.

The first analysis was an assessment of listening performance as it pertained to the CADS. In other words, how did the sample as a whole perform when the mean data from the favorable (+13 dB SNR) and poor condition (+3 dB SNR) are compared? In addition, how did Group 1 and Group 2 perform when the mean data from the acoustic conditions are compared? To answer the first question, a t-test was conducted using a Tukey procedure for post hoc multiple comparisons. The group mean score of 33 participants for the favorable +13 dB signal-to-noise ratio (SNR) condition (87.5%) was compared to their mean score for the poorer +3 dB SNR condition (70.8%). The favorable SNR produced a mean score improvement of 16.8%, $t = 8.26$, and $p < 0.001$.

For the next two questions, the t-test with Tukey adjustment for post hoc multiple comparisons was utilized. The Group 1 mean score of its 16 participants for the favorable +13 dB SNR (89.8%) was compared to their mean score for the poorer +3 dB SNR condition (71.3%). The favorable SNR scenario yielded an improved mean score of 18.8%, $t = 7.97$, and $p < 0.001$. By comparison, the Group 2 mean score of its 17 participants for the favorable +13 dB SNR (85.5%) was compared to their mean score for the poorer +3 dB SNR condition (70.3%). The favorable SNR condition yielded a smaller improved mean score of 15.2%, $t = 4.59$, and $p < 0.001$. Clearly the 10-dB SNR enhancement, or CADS model of +3 versus +13 dB, is an effective acoustical variable.

Given that the primary objective was to (1) investigate the effect of two SNRs on fine-grain discrimination, and (2) examine whether phonetically trained listeners (Group 1) have superior discrimination abilities when compared to un-trained listeners (Group 2), collected data were analyzed using statistical tests wherein requisite assumptions were all satisfied. The +13 signal-to-noise ratio condition was designed to approximate an acoustical environment with a CADS that is turned “on” and functioning properly; whereas, the +3 signal-to-noise ratio condition was designed to approximate a listening environment with a CAD system that is in the “off” position.

In order to address the first objective, mean performance scores for Groups 1 and 2 were analyzed, and two t-tests were conducted to assess performance across SNR conditions. Figure 1 displays performance in percent correct on the discrimination task, for both groups, as a function of each SNR listening condition. In the favorable 13-dB SNR condition, mean task performance for Group 1 was 89.9% as compared to the mean task performance of Group 2 of 85.5%, with a standard deviation of 8% and 12%, respectively. On average, the discrimination performance of Group 1 exceeded Group 2 by more than 4% in the favorable SNR condition; however, a t-test revealed that this difference was not significant, t (31) = .0422, t value = 1.13, p = 0.267. The standard deviation for Group 2 was 50% greater than Group 1, indicating that higher task proficiency resulted in less variable test measurements.

In the poor 3-dB SNR condition, mean task performance for Group 1 was 71.3% as compared to the mean task performance of Group 2 of 70.3%, with standard deviations of 9% and 8%, respectively. The second t-test revealed that this difference was not significant, t (29) = .0092, t value = 0.28, p = 0.779. The differences between the standard deviation statistics were not the same as with the favorable SNR condition, and, for the poor SNR condition, were negligible. These data suggest that phonetic training is not a predictive factor in favorable or poor listening conditions.

In order to address the second objective, participant self-reported proficiency ratings for members of Group 1 were conveniently collapsed into two sub-groups: high and low proficiency. Mean performance scores for the high proficiency (High Pro) and low proficiency (Low Pro) sub-groups were compared and a t-test was used to evaluate performance across SNR conditions. Figure 2 displays performance in percent correct on the consonant-vowel task, for both Group 1 proficiency classification sub-groups (High Pro and Low Pro), as a function of each SNR listening condition. It appears that self-reported high phonetic proficiency is not a factor in favorable or poor listening conditions. Although the data are not reported due to sample size disparities, differences between the performance of male and female subjects were not significant in both SNR conditions.

The survey required respondents to rate themselves as one of the following: *very proficient, proficient, can get by,* or *not proficient*. None of the subjects considered themselves *very proficient*. Of 16 participants in Group 1, nine subjects rated themselves as proficient, which formed the High Pro sub-group, while six subjects chose *can get by* and one *not proficient*, which were combined to form the seven subjects in the Low Pro sub-group. Sub-group performance has been displayed in Table 3 and Figure 2. Although there were no substantive differences between the sub-groups by condition, there were substantial improvements of 20% and 17% when acoustic conditions are improved, for the high proficiency and low proficiency sub-groups, respectively.

The analysis revealed that there was a significant difference in discrimination performance between acoustic conditions, with less discrimination errors made in the more favorable SNR condition. Two conclusions were drawn from this finding. First, it was inferred that the use of a classroom audio distribution system, which typically provide a 10 dB relative advantage over unamplified listening conditions, may improve fine-grain auditory discrimination. Second, it was inferred that speech language pathologists who rely upon their perceptual abilities to perform speech sound analysis of speech sound disorders, might benefit in terms of diagnostic accuracy and precision from a SNR of at least 10 dB. In addition, the data demonstrate a 4.4% difference in discrimination performance between the experimental and control group in the +13 SNR condition; however, the difference was not statistically significant. It is not clear whether this difference may prove to be technically significant.

CHAPTER 4

Discussion

Conclusions

Prior to the study, it was hypothesized that (1) an increased signal-to-noise ratio (SNR) will enhance fine-grain auditory discrimination and (2) phonetic training can improve the detection of fine-acoustic cues that signal consonant contrasts. The findings revealed a significant difference in discrimination performance between acoustic conditions, with better performance in the more favorable SNR condition (+10 SNR). This indicates that maximizing a listener's acoustic environment can enhance fine-grain auditory discrimination. It may also be inferred that assistive listening technologies, such as classroom audio distributions systems (CADS), which typically provide a 10 dB relative advantage over unamplified acoustics, may enhance fine-grain auditory discrimination. This is especially important in view of research that suggests fine-auditory discrimination holds special importance for language learning and school success (Elliot, Hammer, & Scholl, 1989).

It can also be concluded that speech-language pathologists (SLPs) who rely upon their perceptual abilities to diagnose and treat individuals with speech sound disorders, should provide their diagnostic assessments and interventions in the best possible listening environments. SNRs below +10 dB may adversely affect both the client's and the clinician's ability to discriminate between correct and incorrect speech sound productions. The American Speech-Language-Hearing Association (ASHA, 2003) recommends speech therapy rooms in educational settings meet the standard criteria for ambient noise recommended by the American National Standards

Institute (ANSI S12.60-2002). Evidence suggests that speech therapy rooms commonly have acoustic levels that far exceed the ANSI requirements for ambient noise levels in educational settings (Porter & Dancer, 1998). This investigation's findings support the notion that clinical environments should be monitored in order to ensure room acoustics do not interfere with the effective provision of diagnostic and remediation services.

Lastly, results revealed a 4.4% and 1.3% difference in discrimination in mean score performance between subject groups in the +13 SNR and +3 SNR conditions, with G1 performing better than G2 in both conditions. These differences between groups were not statistically significant. It is unknown whether a 4.4% difference in performance between groups is clinically meaningful. All things being equal, a larger sample size may have yielded statistically significant differences between groups. The standard deviation for G2 was 50% greater than G1. This indicates that phonetically trained listeners had less variable discrimination performance than untrained listeners.

A comparison of the G1 phonetic proficiency subgroups revealed a difference of 0.7% and 2.3% in mean score performance between groups in the +13 SNR and +3 SNR conditions, with the high proficiency group performing better than the lower proficiency group in the +13 SNR condition and the low proficiency group performing better than the high proficiency group in the +3 SNR condition. These subgroup differences were not statistically significant. Therefore, reported self-proficiency does not appear to be associated with discrimination performance.

Study Limitations

There are several limitations of the current study that warrant discussion. First, it is possible that response bias may have influenced performance. That is, subjects may have responded either *same* or *different* in preferential manner. *Same/different* discrimination tasks have been shown to be particularly prone to response bias (Sutcliffe & Bishop, 2005). In this study, responses were obligatory and subjects were provided with only two response options; therefore, it may be assumed that subjects generally expected an even number of *same* and *different* trials, or an equal probability of *same/different* appearances, and this assumption may have affected their response judgments. In order to counteract this bias, subjects were not implicitly instructed on the likelihood of *same* or *different* trials. It is unknown whether this strategy of ambiguity was effective in preventing response bias.

Subjects may also have demonstrated bias towards one specific response choice. For example, participant #12 from the non-phonetically trained group performed particularly poorly in the poorer SNR condition (+3 SNR), and appeared to be biased to the *same* response. However, given the low SNR, it is possible the participant did not perceived acoustic differences between contrast pairs, and hence, responded *same*.

Another limitation of the present study was that participant performance was possibly influenced by non-auditory factors such as participant attention and motivation. The discrimination task required allocation of attention to incoming stimuli for nearly 20 continuous minutes. In this context, the discrimination task heavily taxed attentional resources and required a high-level of participant commitment. In order to minimize the effects of higher-order cognitive factors such at participant attention and motivation on discrimination performance, subjects heard a recorded female voice that periodically counted item trials (e.g., “one”, “five”, “ten”, etc.). It has been hypothesized that alerting subjects to the number of trials helps maintain immediate task relevance and motivational levels (Holt & Carney, 2007). In this investigation, verbal reinforcement was utilized between conditions with the goal of maintaining participant motivation (appendix D). Whether the aforementioned measures (i.e., verbal reinforcement and item counting) were effective at minimizing the effects of top-down mechanisms on task performance is unknown; however, it is fair to assume that non-auditory factors may have accounted for a portion of the variance in discrimination performance

Lastly, there was an unequal distribution of gender in the subject sample. Asymmetry in gender resulted in gender bias and prevented more robust inferential findings. Furthermore, subject groups consisted of college-educated young-adults. Therefore, subjects were not representative of the general population or of children and adult populations, which were described previously. Caution must be exercised when attempting to generalize this investigation’s conclusions to children and non-college educated adult populations.

Future Research

If this investigation were to be replicated, it would be helpful to assess each subject’s discrimination abilities before and after phonetic training, as this would have allowed for a more in-depth understanding of the effect of phonetic training on discrimination. The interference of phonetic training on discrimination could not be fully assessed in the present investigation because the design did not allow for the determination of whether group differences were due to (1) phonetic training, (2) clinical experience, or (3) a predisposition toward fine-grain auditory perception. The latter is relevant in view of recent research that suggests phonetically-trained listeners differ from untrained listeners in terms of brain structure, or the size of the left pars opercularis, whose morphologic development occurs in utero and whose neurons are involved in auditory processing and verbal working memory (Golestani, Price, & Scott, 2011). It is possible that group differences may be observed prior to the onset of phonetic training and group differences may be due to innate perceptual predispositions.

Replication of the current investigation might consider measures of discrimination abilities at multiple and temporally varied periods following phonetic training. This might allow for a determination of whether training-related improvements in discrimination can be maintained long-term. Further investigation should consider collecting and analyzing data pertaining to subjects' level of educational attainment (i.e. associate degree, bachelor's degree, master's degree, etc.) and grade point average. Such participant information may allow for a wider analysis of participant performance and potentially reveal correlations between auditory discrimination ability and educational achievement.

TABLES AND FIGURES

Table 1. Sample age characteristics for the groups.

	Group 1	**Group 2**
Number of subjects	16	17
Mean age (years)	23.3	22.1
Standard deviation (years)	1.5	3.7

Table 2. Age characteristics for females and males in the sample.

	Females	**Males**
Number of subjects	24	9
Mean age (years)	22.0	24.7
Standard deviation (years)	2.4	3.0

Table 3. Number of subjects and mean score performance at both SNR conditions for self-reported proficiency on survey for Group 1, re-classified into high proficiency (High Pro) and low proficiency (Low Pro) groups.

	High Pro	**Low Pro**
Number of subjects	9	7
Mean Score: +13 dB SNR	90.0%	89.3%
Mean Score: +3 dB SNR	70.0%	72.3%

Figure 1. Group 1 and 2 discrimination performance for both SNR conditions.

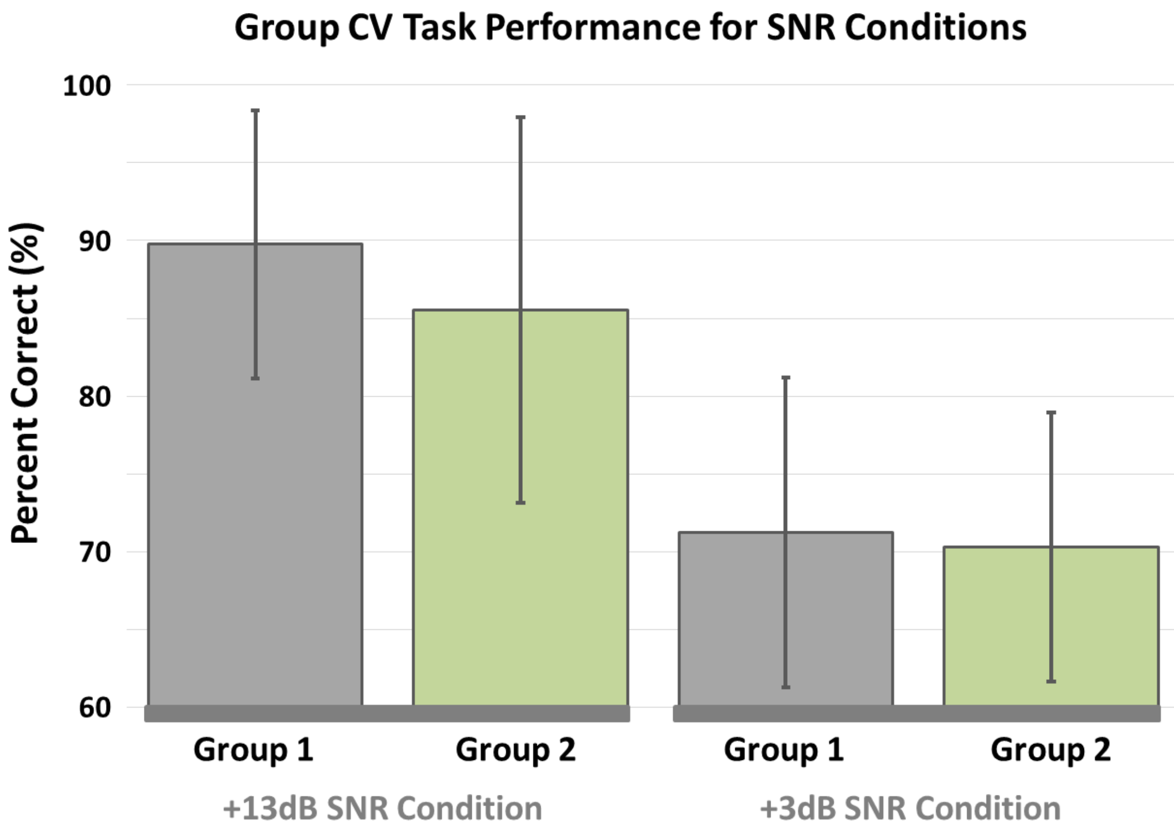
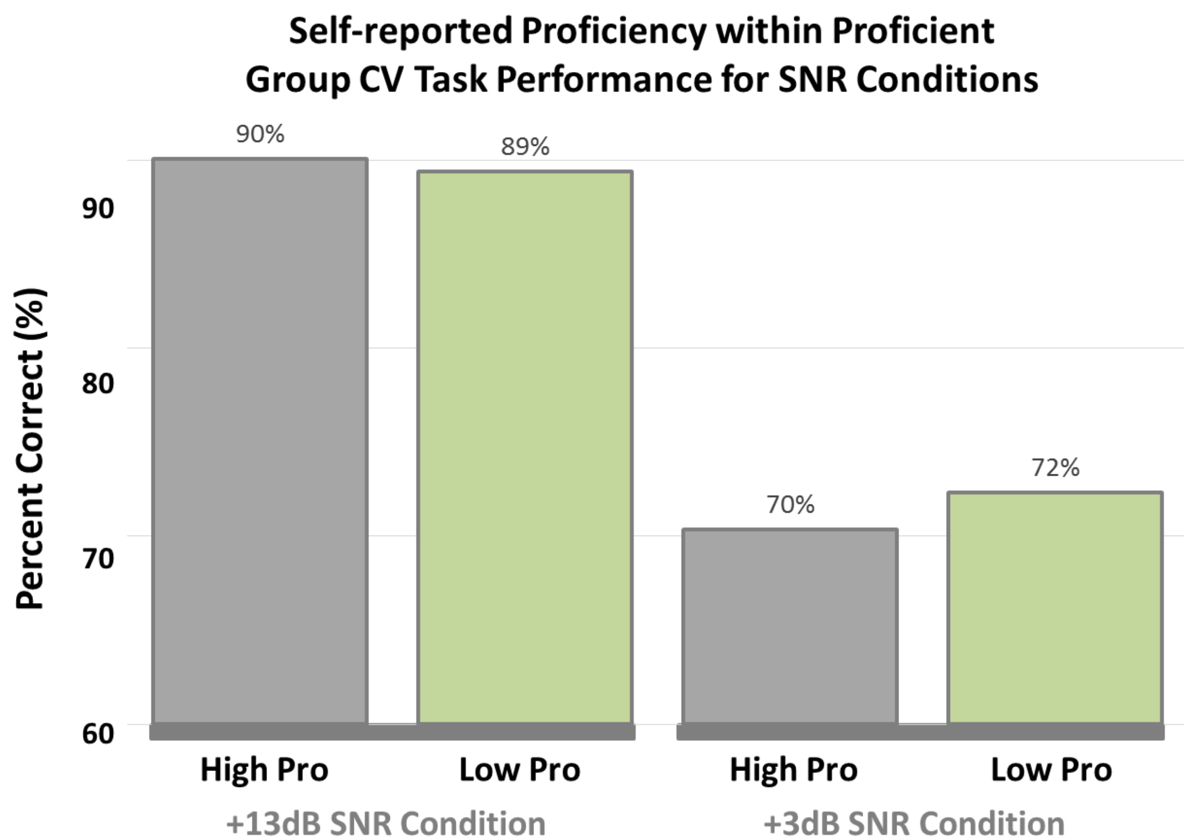


Figure 2. Self-reported proficiency within Group 1 (re-classified into high proficiency or "High Pro" and low proficiency or "Low Pro") for discrimination performance in both SNR conditions.



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APPENDICES

Appendix A: Consent Form

Participant Consent Form

Project Description:
You are invited to participate in a research study titled, "The Effects of Phonetic Training on Fine-grain Auditory Discrimination." This study is being conducted by Ryan Mulligan and Joseph Smaldino, Ph.D., from the Department of Communication Sciences and Disorders at Illinois State University. The goal of the study is to determine how personal experience, such as phonetics training, affects auditory discrimination.

Participation:
You were selected as a potential participant in this study because you are a student attending Illinois State University. In order to participate, you must be a native English speaker, and be at least 18 years old. You will not be able to participate in this research study if you have a known hearing loss.

Description of Procedures:
If you choose to participate in the study, you will complete a hearing screening. If you pass the screening, you will participate in an auditory discrimination task. The auditory discrimination task will involve differentiating between two speech sounds that are presented in quick succession (i.e. stimuli pairs). You will be asked to indicate whether the presented paired stimuli were the "same" or "different." If the two paired stimuli are same, you will fill-in the A-oval on your scantron sheet. If the two paired stimuli are different, you will fill-in the B-oval on your scantron sheet. Total participant commitment is approximately 45 minutes.

Risks and Benefits of Participation:
There are no significant physical risks anticipated in the study. The hearing screening involves common clinical procedures routinely performed in the field of audiology. In the advent hearing loss is identified, you will be told you did not pass the hearing screening and will be given a recommendation for a comprehensive hearing evaluation at the Eckelmann-Taylor Speech and Hearing Clinic at Illinois State University.

There is minimal risk that you will feel slight discomfort and boredom during both the hearing screening and the auditory discrimination task. There is also a possibility that you might feel uncomfortable providing personal information such as age, gender, college major, and information pertaining to phonetic training (if applicable). Additionally there is a risk confidentially will be breached. However, all necessary precautions will be made to minimize this risk. Identification numbers will be used instead of names and results will be stored on a password-protected computer. Only the principal and co-principal investigator will have access to participant information.

There is no guarantee that you will benefit from participation in this study. However, you could potentially benefit from knowing whether you have normal hearing sensitivity.

Voluntary Consent to Participate:
Your participation is completely voluntary and you may withdraw from the study without negative repercussions at any time. Your decision to participate in the study will not affect your class grades or your academic standing at Illinois State University. The study has been reviewed and approved by The Institutional Review Board at Illinois State University.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE.

If at any time, either now or later, you have a question, please feel free to contact Dr. Joseph Smaldino (jsmaldi@ilstu.edu; 309-438-7061), and/or Ryan Mulligan (rcmulli@ilstu.edu) in the Department of Communication Sciences and Disorders at Illinois State University. If you want to talk to someone about any complaints or your rights as a participant in this study, you may contact the Illinois State University Research Ethics & Compliance Office at (309) 438-2520, rec@IllinoisState.edu.

____

Signature of participant Date

____

Signature of investigator Date

Appendix B: Participant Survey

Participant Survey

Participant Number:________________

Please answer the following questions:

1. What is your age?

2. What is your gender?

3. What is your academic major?

4. Have you successfully completed a college-level phonetics course with a grade B or better? ____Yes ____No. If yes, complete the following:

    a. How long has it been since your last phonetics course (e.g. Fall semester 2014)?

    b. How proficient do you feel you are at using phonetics?
        i. Very proficient
        ii. Proficient
        iii. Can get by
        iv. Not proficient

Appendix C: Participant Directions

Participant Directions

Thank you for your participation in the study. Your decision to participate will not affect your class grades or your academic standing at Illinois State University. Your involvement is completely voluntary and you may withdraw from the study without negative repercussions at any time.

Upon passing a short hearing screening, you will take part in an auditory discrimination task. The task will take place in a sound-booth and you will hear speech sound contrasts being presented via insert headphones. You task is to determine whether the contrastive speech sounds are the "same" (e.g. [ba-ba]) or "different" (e.g. [ba-da]). **If the speech sounds are the same, you will fill-in the A-oval on your Scantron sheet. If the speech sounds are different, you will fill-in the B-oval on your Scantron sheet.**

For example, if you heard the speech sounds [ba-ba] you would indicate that the speech sounds are identical by filling in the A-oval on your Scantron sheet. If you heard the speech sounds [da-ga], you would indicate that the stimuli are different by filling in the B-oval on your Scantron sheet. The only speech sounds you will hear are /ba/, /da/, /ga/; no other speech sounds will be included in the discrimination task.

There are only six seconds between contrastive speech sound presentations. Therefore, you should quickly fill in the A or B ovals on your Scantron sheet. There are two discrimination conditions and each condition is approximately 18 minutes long. During both conditions you will hear a constant "speech noise." Please ignore the noise and concentrate on hearing the speech sounds.

The entire discrimination task will take approximately 36 minutes.

Do you have any questions?

Appendix D: Verbal Reinforcement

Participant Reinforcement

You are halfway through with the discrimination task. During this next, condition the noise level will be higher/lower (*participant specific*). **Thank you for your effort**! You only have one more condition to go.